Calculation of Area and Volume for the South Part of Great Salt Lake, Utah

Prepared in cooperation with the Utah Department of Natural Resources, Division of Wildlife Resources

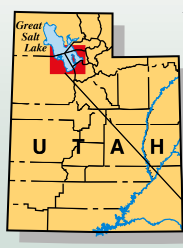
By Robert L. Baskin

Abstract

The U.S. Geological Survey, in cooperation with the Utah Department of Natural Resources, Division of Wildlife Resources, collected bathymetric data for the south part of Great Salt Lake during 2002–04 using a single-beam, high-definition fathometer and real-time differential global positioning system. About 7.6 million depth measurements were collected along more than 930 miles (1,690 kilometers) of survey transects. Sound-velocity profiles were obtained in conjunction with the bathymetric data to provide time-of-travel corrections to the depth calculations. Data were processed with commercial hydrographic software and exported into geographic information system (GIS) software for mapping and calculation of area and volume. Area and volume calculations show a maximum area of about 508,000 acres (2,056 square kilometers) and a maximum volume of about 9,257,000 acre-feet (11.42 cubic kilometers) at a water-surface altitude of 4,200 feet (1,280 meters). Minimum water-surface altitude of the south part of Great Salt Lake is just below 4,167 feet (1,279 meters) in the area just south of the Union Pacific railroad causeway halfway between Promontory Point and the western edge of the lake. At this altitude, and continuing up to about 4,176 feet (1,279 meters), the south part of the lake is separated into two areas by a ridge extending from Promontory Point to Hat Island. Calculations for area and volume are based on a low altitude of 4,167 feet (1,279 meters) to a high altitude of 4,200 feet (1,280 meters).

Introduction

Prior to the 1980s, detailed information about many aspects of Great Salt Lake, including bathymetric data, was scarce. Flooding in the early 1980s increased concern for avian resources and the lake ecosystem, and the emergence of the brine shrimp industry created both public interest and management concern. To fill the need for a better understanding of the physical and chemical characteristics of the lake, how the lake functions, and how man is affecting these characteristics and functions, the U.S. Geological Survey (USGS), in cooperation with the Utah Department of Natural Resources, Division of Wildlife Resources, collected bathymetric data for the south part of Great Salt Lake (fig. 1) during 2002–04 using a single-beam, high-definition fathometer and real-time differential global positioning system. These data were collected to better define the physical characteristics of the south part of the lake, define the areal extent of a deep high-density brine layer, provide data for improved calculation of area and volume, and provide lake-bottom contour information that could be used in developing a general circulation model of the lake. This bathymetric study was part of a larger, long-term, multi-discipline, cooperative study designed to (1) define the physical constraints, circulation, and mixing rates of Great Salt Lake; (2) determine the nutrient (nitrogen and phosphorous species) budget of the lake, and (3) quantify the occurrence and distribution of anthropogenic heavy metals, trace elements, and synthetic organic compounds in the lake.



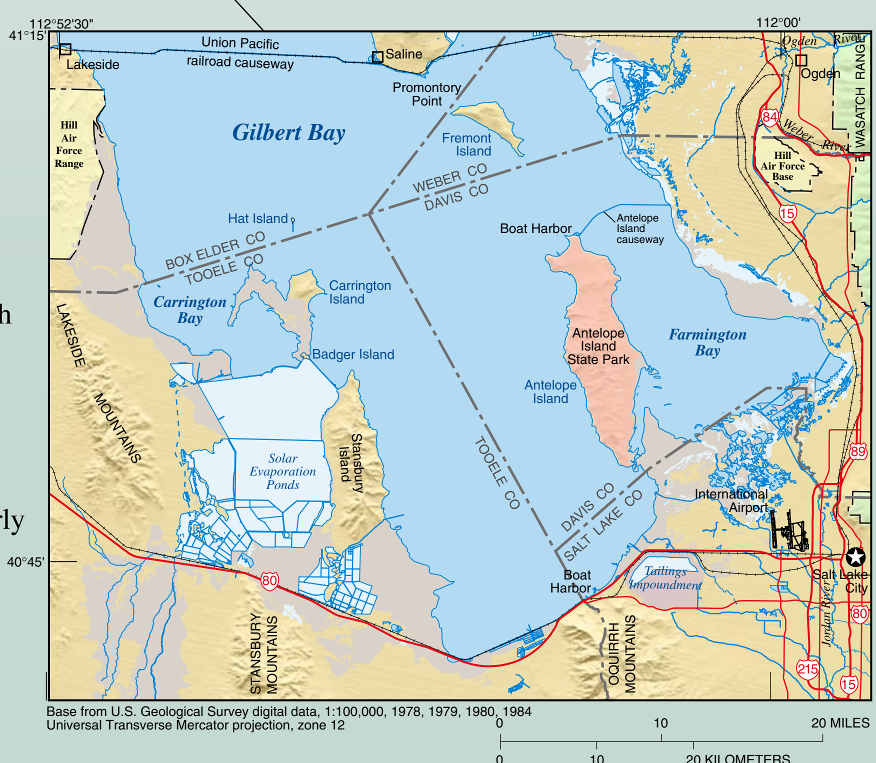


Figure 1. Map showing south part of Great Salt Lake and vicinity, Utah.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2005**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Calculation of Area and Volume for the South Part of Great Salt Lake, Utah**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Department of the Interior 1849 C Street NW Washington, DC 20240**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

About 7.6 million depth measurements were collected along more than 930 miles (1,690 kilometers) of survey transects (fig. 2) during the data-collection phase of this study. Sound-velocity profiles were obtained in conjunction with the bathymetric data to provide time-of-travel corrections to the depth calculations. Data were processed with commercial hydrographic software and exported into geographic information system (GIS) software for mapping and calculation of area and volume. Because of the shallow nature of the lake and the limitations of the instrumentation, contours above an altitude of 4,193 feet (1,278 meters) were digitized from existing USGS 1:24,000-scale topographic quadrangle maps. A triangulated irregular network generated from the bathymetric data and digitized contours were used for the calculations of area and volume.

This report describes the methods and data used to calculate the area and volume of the south part of Great Salt Lake at 0.5-foot intervals from an altitude of 4,167 feet (1,279 meters) to 4,200 feet (1,280 meters).

Description of Study Area

Great Salt Lake is a terminal lake in the northwestern part of Utah; changes in water-surface altitude are determined by differences between net inflow and evaporation from the surface of the lake. Inflow to the lake is affected by impoundments on and diversions from streams that flow into the lake. At a water-surface altitude of 4,200 feet (1,280 meters), the lake has a surface area of about 1,660 square miles (4,300 square kilometers) and an average depth of 14.6 feet (4.45 meters). In 1963, Great Salt Lake was at its lowest water-surface altitude in recent history (about 4,191 feet (1,277 meters)), covered about 950 square miles (2,460 square kilometers), and had a maximum depth of about 25 feet (7.6 meters). In 1986, Great Salt Lake was at its highest water-surface altitude in recent history (about 4,212 feet (1,284 meters)), covered about 2,400 square miles (6,216 square kilometers), and had a maximum depth of about 45 feet (13.7 meters). The area of the lake surveyed and used for these calculations includes that part of the lake south of the Union Pacific railroad causeway, north of the Antelope Island causeway, and outside of the solar evaporation ponds and dikes north and west of Stansbury Island (fig. 1). Maximum altitude used in the calculation of area and volume in this report is 4,200 feet (1,280 meters).

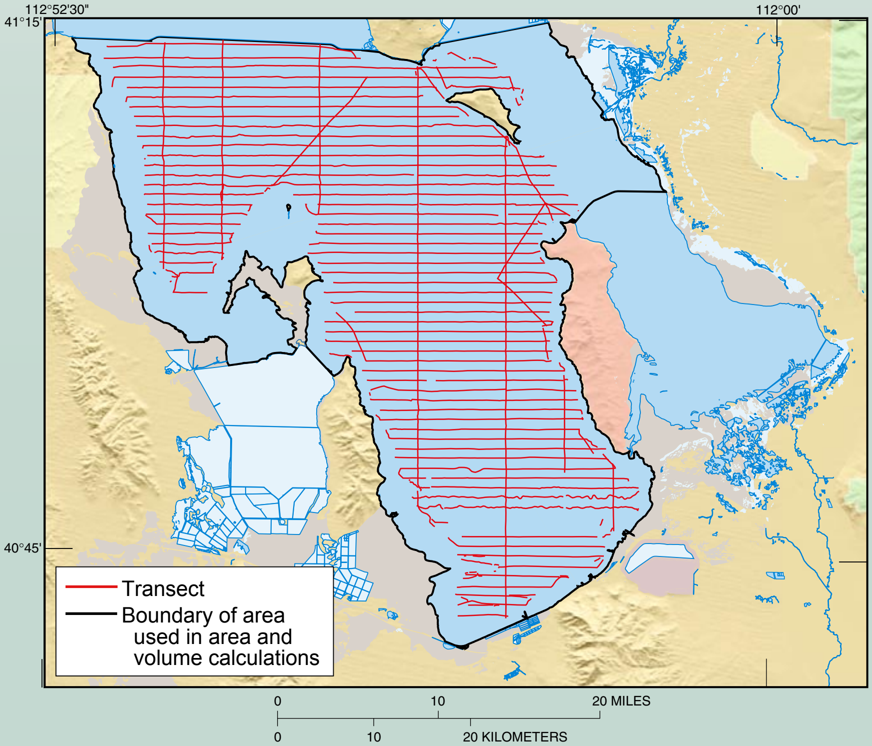


Figure 2. Map showing location of survey transects and boundary of area used in area and volume calculations for south part of Great Salt Lake, Utah.

Methods

Data Collection

Bathymetric data were collected over the navigable areas of the south part of Great Salt Lake during the fall of 2002, the first half of 2003, and the spring of 2004. An automated system consisting of a digital and analog (paper chart) single-beam fathometer coupled to a real-time, differentially corrected global positioning system with the data logged into a navigational computer was used for the basic position/depth data collection. Depths were derived indirectly by measuring the time required for a sonar signal to travel from the transmitter to the bottom of the lake and back to a receiver. Measured sound velocities were used to calculate corrections to the basic time-of-travel data and provide a velocity-corrected distance between the transmitter and receiver. Distance from lake surface to the transceiver face was measured and added to the distance between the transducer and lake bottom to derive the calculated depth of the lake. Analog paper records were collected during the survey at selected locations to cross-check digital readings and provide detail of bottom features during the collection of field data.

About 913 miles (1,690 kilometers) of transects were collected primarily on east-west transects spaced about 0.62 miles (1 kilometer) apart and including seven north-south transects (fig. 2). Position data were recorded at about a 1-second rate and depth data at about 15 points per second. Vessel speed was limited to less than 10 miles per hour (16 kilometers per hour) to maximize the number of depth measurements gathered during the data-collection phase. Quality-control considerations limited the periods of data collection to times when the lake surface had no noticeable swell and waves generally were less than 6 inches (0.15 meter). Because of the high sound velocity (a result of the higher density water) and limitations in the instrumentation, data collection was limited to areas deeper than about 3 feet (1 meter).

Water depth was measured with a survey-grade Reson, Inc.[1], model 210 single-beam

[1] Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S Geological Survey.

echosounder using a 2.7-degree beam width and 200 kilohertz transducer. Manufacturer specifications for this echosounder indicate that the depth of operation is from 0.2 to 600 meters (0.7 to 1,969 feet) and that the depth measurement accuracy is 1 centimeter (0.4 inch). Speed of sound for the data-collection segment of this survey was set at a constant 1,600 meters per second (5,250 feet per second). Speed-of-sound corrections were subsequently applied during data processing.

Sound-velocity profiles were collected at several times and locations throughout the survey with a direct "time-of-flight" sound-velocity sensor. Sound-velocity data were collected at 38 sites in Great Salt Lake at 1-meter (3.28-foot) vertical intervals. The sound-velocity sensor used during this investigation was accurate to plus or minus 0.25 meter per second (0.8 foot per second) in water with a 0.2 meter per second (0.7 foot per second) resolution. These data were written into sound-velocity correction files and used during data processing.

Horizontal position data (latitude and longitude) were obtained with a Trimble AG132 integrated Global Positioning System (GPS)/ Differential Global Positioning System (DGPS) coupled with an OmniSTAR Wide Area DGPS Solution. The integrated GPS/DGPS is capable of improving regular GPS accuracies to sub-meter accuracy by solving for atmospheric delays and weighting of distant base stations. Data were collected and processed while surveying and recorded with the unprocessed depth data while in the field. Position data were collected only during times of good satellite visibility and when OmniSTAR Wide Area DGPS Solution differential corrections were available. Differentially corrected data were acquired for all data obtained during this study and positional accuracy is estimated to be 1 meter (3.28 feet) or less.

The PC-based Windows navigational and bathymetric mapping software, Hypack Max, by Coastal Oceanographics, Inc., was used to plan and manage the hydrographic surveys and edit and manage the bathymetric data collected at each lake transect. This software was installed on a portable computer interfaced with the DGPS and survey-grade depth sounder for navigational use. Hypack Max was configured to display and track the vessel position against a background of survey control lines (fig. 3) and later used in the office for processing of the bathymetric data.

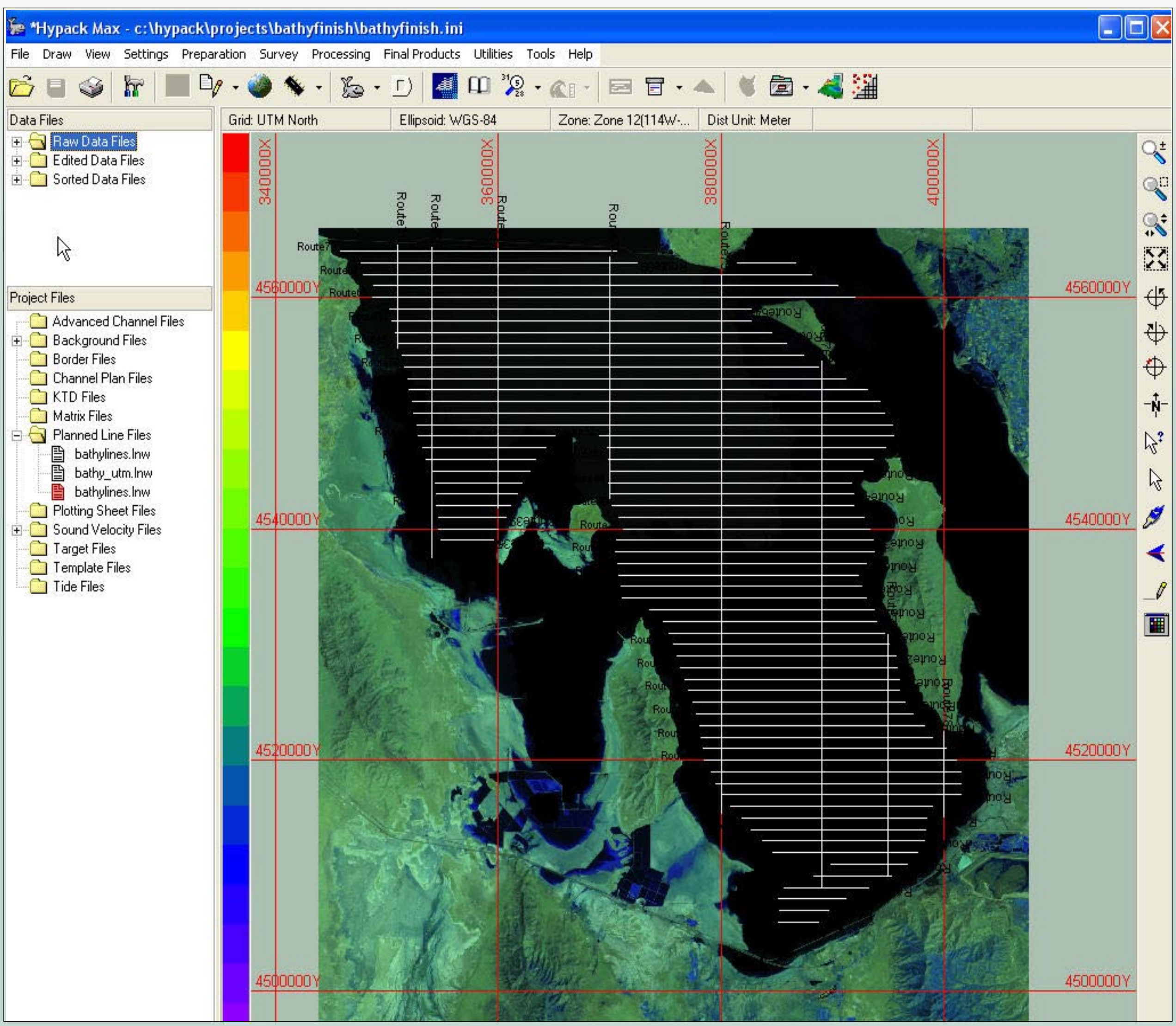


Figure 3. Navigation screen used in survey control of south part of Great Salt Lake, Utah.

Data Processing

Strict controls on data quality were enforced and no data were included in the processing that showed systematic roll or vertical boat movement. Relative positions of the DGPS antenna and echosounder transducer were fixed during the survey period to assure accurate horizontal control. Depth to transducer was physically measured, recorded in the field, and used in processing of the data. Raw data were processed in Hypack Max and exported into an X-Y-Z (latitude-longitude-depth) format for importing into a GIS.

Initial processing of the data included the manual removal of spurious data points (outliers) such as single-point depths located substantially above or below the general lake-bottom trend, zero depths, or data that showed roll or vertical boat movement (fig. 4). Outliers were generally the result of submerged debris, gas bubbles in the water column, or sudden changes in sound velocity resulting from varying salinity. Outliers were visually identified, tagged for deletion, and removed before additional data processing. The resultant data were then corrected for sound velocity by applying the profile data to the raw depth data collected during the survey. Depth from the lake surface to the active face of the transducer was added to the sound-velocity-corrected depths to calculate depth below water surface.

To maximize the amount of depth information acquired during this investigation, depth data were recorded at a frequency of 10 hertz. Differentially corrected positional data were recorded at a frequency of 1 hertz. As a result, about three to five depth measurements were recorded for every meter of survey line depending on actual vessel speed. About 7.6 million discrete depth measurements were initially collected along more than 930 miles (1,690 kilometers) of survey transects and processed during this survey. To reduce the number of data points and to remove minor bottom-surface variations, an average depth was calculated every 5 meters (16 feet) along each processed survey line, and the averaged depth below lake surface was used in defining the bathymetric surface of the lake. Approximately 381,000 averaged depth measurements were calculated and used in the final data analysis.

Depth and location data in an X-Y-Z format were imported into the ArcGIS GIS software package for additional processing. Daily average water-surface altitude data (based on the USGS recorded water-surface altitude) were used to adjust the processed depth-below-water-surface values to altitude. Corrected depth was subtracted from the daily average water-surface altitude for the day the original data were collected to provide lake-bottom altitude along the surveyed transects.

Areas of the lake unavailable for survey because of physical barriers or shallow conditions were digitized from USGS 1:24,000 digital line graphs at a scale of about 1:5,000. These contours ranged from the 4,193 feet (1,278 meters) contour through the 4,200 feet (1,280 meters) contour and included all areas of Great Salt Lake south of the Union Pacific railroad causeway. These digitized contours were incorporated into the bathymetric data set as fixed data contours and used in the calculation of area and volume.

Generation of Bathymetric Surface

The data points defining the bottom surface of the lake were compiled into a single data file, combined with the digitized contours, and processed into a triangulated irregular network for contour generation and subsequent calculation of area and volume. A triangulated irregular network is defined as a set of adjacent, non-overlapping triangles computed from irregularly spaced points with x, y coordinates and z values. The triangulated-irregular-network model stores the topological relations between triangles and their adjacent neighbors; for example, which points define each triangle and which triangles

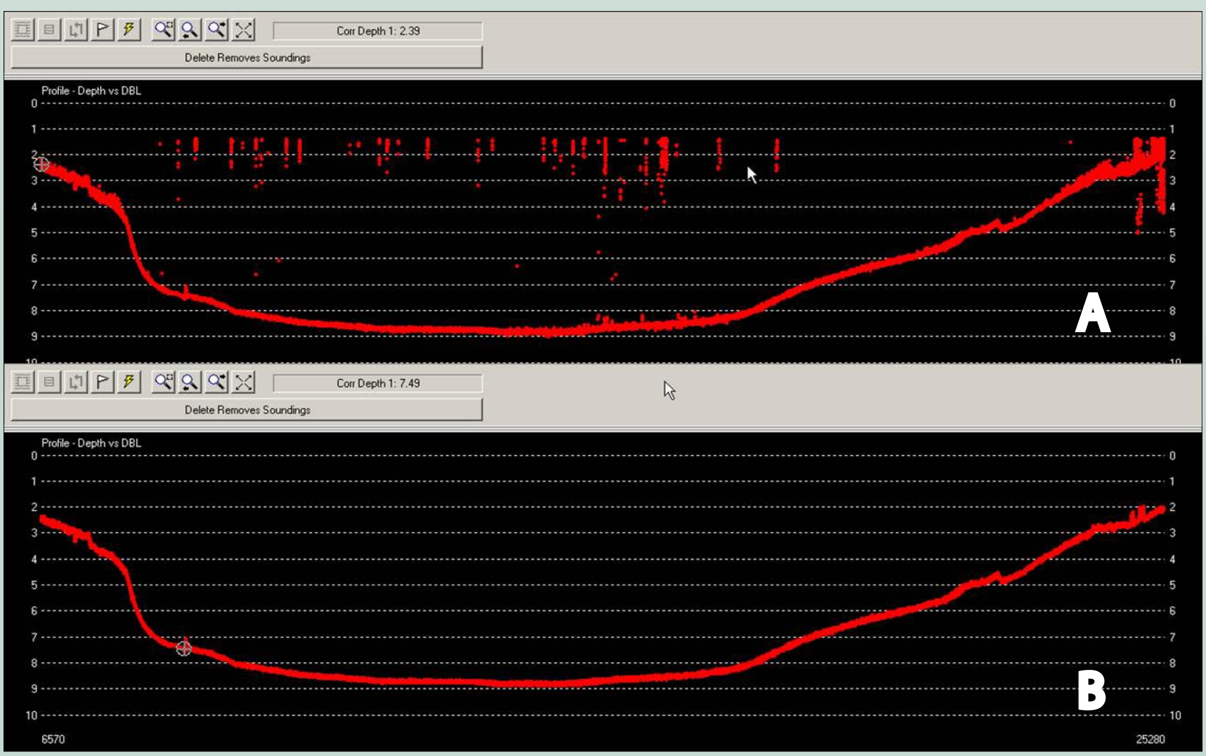


Figure 4. Example survey transect before (A) and after (B) removal of outliers, south part of Great Salt Lake, Utah.

are adjacent to each other (Environmental Systems Research Institute, Inc., 2004). Each of these triangles has a surface area and an average depth. The triangulated-irregular-network contouring function interpolates straight lines across each triangle that span the contour value by using linear interpolation between the edge endpoints to determine where the contour crosses the face. The contoured lake-bottom surface for Great Salt Lake was originally computed in 1-foot intervals from altitudes of 4,167 feet (1,279 meters) to 4,200 feet (1,280 meters) and subsequently used as a guide for contouring of the lake-bottom bathymetric surface. As a result of the spacing and orientation of the survey transects, the computer-interpolated contour lines were problematic in areas of high relief. The computer-contoured data were examined and manually recontoured in areas of high relief, primarily those areas west of Hat Island and Antelope Island. The resultant contours were mapped and published in Baskin and Allen (2005) (fig. 5). The interpreted contour data from Baskin and Allen (2005) are used as the basis for the calculation of area and volume in this report.

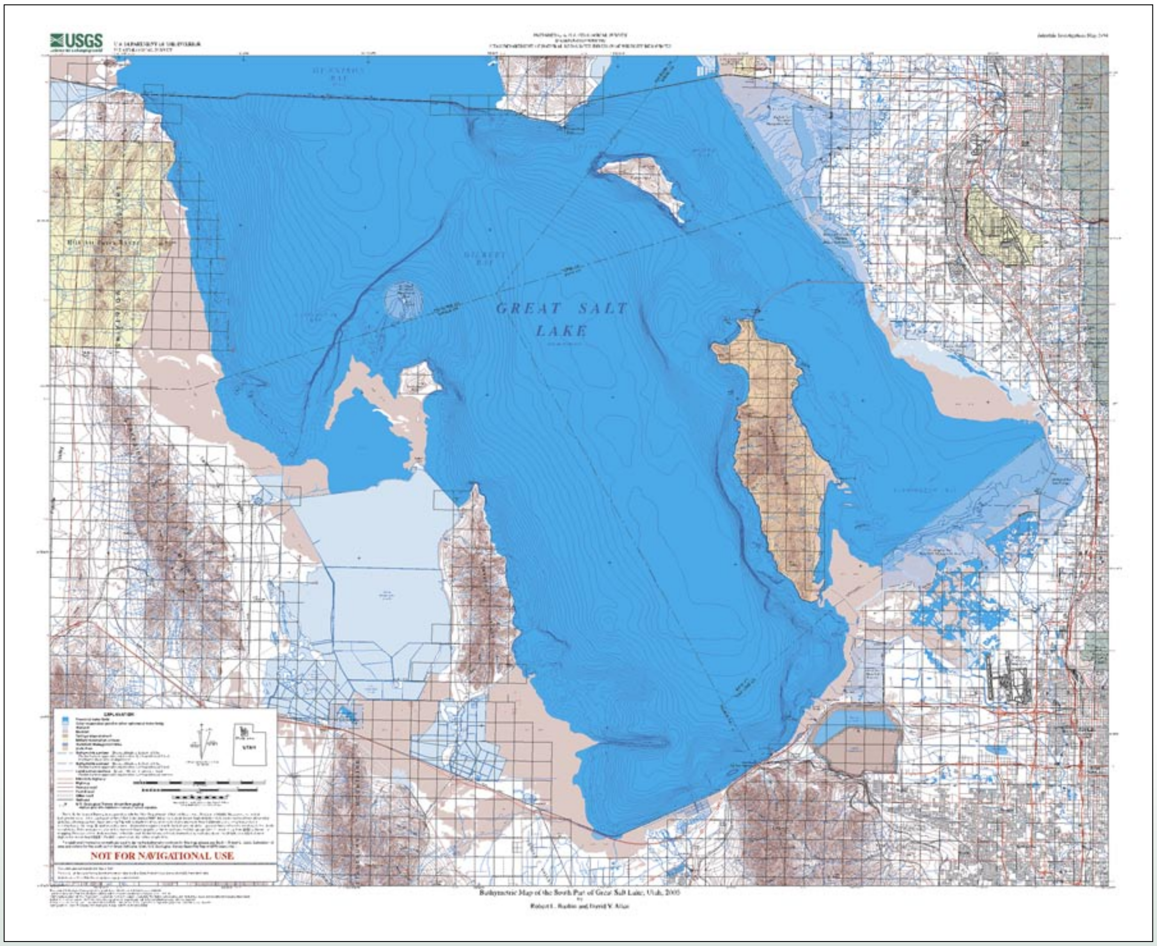


Figure 5. Bathymetric map of the south part of Great Salt Lake, Utah (Baskin and Allen, 2005).

Calculation of Area and Volume

Area and volume were calculated with the 3-D surface analysis package in ArcGIS 8.3 (Environmental Systems Research Institute, Inc., 2004). For each altitude, the triangulated irregular network is examined to determine the area and volume of each triangle contained within the limits of that particular altitude. The sum of these triangles is used for the output of area and volume. Output from the calculation of area and volume was tabled and converted to acres and acre-feet for use in this report (table 1).

Values contained in table 1 are for areas of Great Salt Lake south of the Union Pacific railroad causeway, north of the Antelope Island causeway, and outside of the solar evaporation ponds and dikes north and west of Stansbury Island (fig. 2). The 4,200-foot (1,280-meter) contour digitized from USGS 1:24,000-scale quadrangle maps was used to limit the Great Salt Lake triangulated irregular network such that interpolation could not occur outside of that contour. Additional areas representing the 4,200-foot (1,280-meter) contour for Fremont and Hat Island were removed from the final triangulated irregular network. The triangulated irregular network also incorporated the vertices of the 4,193 to 4,200-foot (1,278 to 1,280-meter) contours as additional points.

Calculations of area and volume for the south part of Great Salt Lake show a maximum area of about 508,000 acres (2,056 square kilometers) and a maximum volume of about 9,257,000 acre-feet (11.42 cubic kilometers) at a water-surface altitude of 4,200 feet (1,280 meters). Minimum water-surface altitude of the south part of Great Salt Lake is just below 4,167 feet (1,279 meters) in the area just south of the Union Pacific railroad causeway halfway between Promontory Point and the western edge of the lake. At this altitude and continuing up to about 4,176 feet (1,279 meters), the south part of the lake is separated into two areas by a ridge extending from Promontory Point to Hat Island. Calculations for area and volume for these separate areas of the lake were combined into a single value as reported in table 1.

Summary

The USGS, in cooperation with the Utah Department of Natural Resources, Division of Wildlife Resources, collected bathymetric data for the south part of Great Salt Lake during 2002–04 using a single-beam, high-definition fathometer and real-time differential global positioning system. About 7.6 million depth measurements were collected along more than 930 miles (1,690 kilometers) of survey transects. Sound-velocity profiles were obtained in conjunction with the bathymetric data to provide time-of-travel corrections to the depth calculations. Data were processed with commercial hydrographic software and exported into GIS software for mapping and calculation of area and volume.

Area and volume values were calculated for areas of Great Salt Lake south of the Union Pacific railroad causeway, north of the Antelope Island causeway, and outside of the solar evaporation ponds and dikes north and west of Stansbury Island. The 4,200-foot (1,280-meter) contour digitized from USGS 1:24,000-scale quadrangle maps was used to limit the Great Salt Lake triangulated irregular network such that interpolation could not occur outside of that contour. Additional areas representing the 4,200-foot (1,280-meter) contour for Fremont and Hat Island were removed from the final triangulated irregular network. The triangulated irregular network also incorporated the vertices of the 4,193 to 4,200-foot (1,278 to 1,280-meter) contours as additional points.

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References Cited

Baskin, R.L., and Allen, D.V., 2005, Bathymetric map of the south part of Great Salt Lake, Utah: U.S. Geological Survey Scientific Investigations Map 2894.

Environmental Systems Research Institute, Inc., 2004, ArcToolbox: About surfaces and surface models, ArcGIS 9.0 Desktop Help, accessed June 2005 at *http://webhelp.esri.com/arcgisdesktop/ 9.1*

Table 1. Water-surface altitude, area, and volume of south part of Great Salt Lake, Utah

[Values calculated for the area of Great Salt Lake south of the Union Pacific railroad causeway, north of the Antelope Island causeway, and outside of the solar evaporation ponds and dikes north and west of Stansbury Island]

Water-surface altitude (in feet)[1]	Area (acres)	Volume (acre-feet)
4,167.0	3,554	24
4,167.5	4,597	2,046
4,168.0	5,886	4,649
4,168.5	11,616	9,685
4,169.0	35,015	16,373
4,169.5	55,607	39,059
4,170.0	77,466	72,181
4,170.5	93,926	115,732
4,171.0	109,681	166,316
4,171.5	121,102	223,859
4,172.0	132,669	287,548
4,172.5	146,134	357,825
4,173.0	156,203	433,220
4,173.5	164,270	513,709
4,174.0	172,214	597,601
4,174.5	180,329	686,168
4,175.0	188,045	778,020
4,175.5	195,002	873,658
4,176.0	201,595	973,171
4,176.5	207,368	1,075,140
4,177.0	213,281	1,180,712
4,177.5	219,204	1,288,564
4,178.0	225,292	1,399,360
4,178.5	231,127	1,513,912
4,179.0	236,974	1,630,628
4,179.5	243,609	1,751,287
4,180.0	250,409	1,874,427
4,180.5	255,853	2,000,657
4,181.0	261,434	2,130,483
4,181.5	267,342	2,262,432
4,182.0	273,468	2,398,053
4,182.5	278,723	2,535,727
4,183.0	284,257	2,676,091
4,183.5	289,993	2,820,376
4,184.0	295,296	2,966,284
4,184.5	300,645	3,115,836
4,185.0	306,434	3,267,187
4,185.5	312,557	3,421,729
4,186.0	318,192	3,579,978
4,186.5	322,838	3,739,811
4,187.0	327,633	3,903,064
4,187.5	335,096	4,068,723
4,188.0	341,788	4,237,312
4,188.5	347,346	4,410,271
4,189.0	352,939	4,584,880
4,189.5	360,198	4,764,287
4,190.0	366,313	4,945,311
4,190.5	370,993	5,129,154
4,191.0	375,701	5,316,562
4,191.5	380,914	5,505,278
4,192.0	386,122	5,697,760
4,192.5	391,339	5,891,605
4,193.0	396,811	6,088,115
4,193.5	404,222	6,289,675
4,194.0	409,868	6,492,562
4,194.5	415,739	6,699,756
4,195.0	422,042	6,908,632
4,195.5	440,014	7,126,200
4,196.0	448,170	7,348,790
4,196.5	455,190	7,574,031
4,197.0	462,422	7,804,330
4,197.5	470,166	8,037,446
4,198.0	475,438	8,273,227
4,198.5	484,154	8,514,807
4,199.0	489,901	8,757,682
4,199.5	499,019	9,006,237
4,200.0	508,331	9,257,326

[1]Altitude referenced to National Geodetic Vertical Datum of 1929 (NGVD 29).